Another useful reference is "Non-ionizing Radiation-Measurement Methods and Artifacts", by E. Aslan (Reference 16), which provides information on measurement techniques and potential sources of error.

"A Practical Guide to Determination of Human Exposures to Radiofrequency Radiation" (Reference 17) prepared by Scientific Committee 89-2 of the National Council on Radiation and Measurements (NCRP), is expected to be published by the end of 1993 or early 1994. That document, relied on to a great extent in the discussion herein, has sections on basic concepts, procedures for evaluation of exposures, instruments and measurement techniques, and an extensive appendix directed to hazard evaluation procedures for specific applications. When available from NCRP, this document is likely to be the most comprehensive, and current source available with respect to instrumentation and procedures.

The NCRP has published NCRP Report No. 67, "Radiofrequency Electromagnetic Fields, Properties, Quantities and Units, Biophysical Interaction, and Measurements" (Reference 18). This report is a useful compilation of the physical principles involved in analyzing the RF radiation problem and contains a chapter on measurements.

The Environmental Protection Agency (EPA) has issued a report entitled "Radiofrequency Measurements Workshop, Workshop Summary (Reference 19). This report is a summary of a 1980 workshop held at EPA to consider the various problems involved in measuring close-in RF fields for purposes of exposure assessment. This document contains information on the possible limitations of various instruments and on problems that may arise in making these types of measurements. Also, Reference 20, by R.A. Tell, contains an overview of RF instrumentation and measurements.

Instrumentation

Instruments used for measuring radiofrequency electromagnetic fields may be either broadband or narrowband devices. A typical broadband instrument responds essentially uniformly and instantaneously over a wide frequency range and requires no tuning. A narrowband instrument may also operate over a wide frequency range, but the instantaneous bandwidth may be limited to only a few kHz, and the device must be tuned to the frequency of interest. One device that can cover a broad band, but still provide information in discrete frequency bands is the spectrum analyzer. Each type of instrument has certain advantages and disadvantages. The choice of which instrument to use depends on the situation where measurements are to be made.

Except for the spectrum analyzer that has its own requirements for peripherals necessary for its use in the measurement of electromagnetic fields, all instruments used for measuring RF fields have the following basic components: (1) an antenna to sample the field, (2) a detector to convert the time-varying output of the antenna to a steady-state or slowly varying signal, (3) electronic circuitry to process the signal, and (4) a readout device to display the measured field parameter in appropriate units. Spectrum analyzers are not designed specifically for the measurement of RF fields, but can accept the RF output of a broadband antenna and display voltage levels versus frequency. However, the voltage level as read on the spectrum analyzer must be corrected by the antenna characteristics and transmission line loss to determine field strength. With a spectrum analyzer containing an appropriate output port, microprocessor and printer, the conversion can be accomplished automatically.

The antennas used with broadband instruments are either dipoles that respond to the electric field (E) or loops that respond to the magnetic field (H). In order to achieve a uniform response over the indicated frequency range, the size of the dipole or loop must be small compared to the wavelength of the highest frequency to be measured. Isotropic broadband probes contain three mutually orthogonal dipoles or loops whose outputs are summed so that the response is independent of orientation of the probe. The output of the dipoles or loops is converted to a proportional steady-state voltage or current by diodes or thermocouples, so that the measured parameter can be displayed on the readout device.

Certain characteristics are desirable in a broadband survey instrument (Reference 15 and 17). The major ones are as follows:

(1) The response of the instrument should be essentially isotropic, *i.e.*, independent of orientation, or rotation angle, of the probe.

(2) The frequency range of the instrument and the instrument's response over that range should be known. Generally this is given in terms of error response between certain frequency limits, *e.g.*, ± 0.5 dB from 3-500 MHz.

(3) Out-of-band response characteristics of the instrument should be specified by the manufacturer to assist the user in selecting an instrument for a particular application. For example, regions of enhanced response, or resonance, at frequencies outside of the band of interest could result in error in a measurement if signals at the resonant frequency(ies) are present during the measurement.

(4) The dynamic range of the instrument should be approximately ± 10 dB of the applicable exposure guideline.

(5) The instrument's readout device should be calibrated in units that correspond to the quantity actually being measured. An electric field probe responds to E or E^2, and a magnetic field probe responds to H or H^2, equally well in both the near-field and far-field. However, a readout device calibrated in units of power density does not read true power density if measurements are made in the near-field. This is because plane-wave conditions, in which E, H, and power density are related in a known way, do not exist in the near-field where the wave impedance is complex and generally not known. Readout devices calibrated in "power density" actually read "far-field equivalent" power density or "plane-wave equivalent" power density (see discussion of ANSI/IEEE guidelines in Section I).

(6) The probe should respond only to the parameter being measured, *e.g.*, a loop antenna element should respond to the magnetic field only and should not interact significantly with the electric field.

(7) Shielding should be incorporated into the design of the instrument to reduce or eliminate electromagnetic interference.

(8) Some means should be provided, *e.g.*, an alarm or test switch, to verify that the probe is operating correctly and that none of the elements is burned out. Also, a means should be provided to alert the user if the measured signal is overloading the device.

(9) When the amplitude of the field is changing while measurements are being made, a "peak-hold" circuit may be useful. Such a change in amplitude could result either from variation in output from the source or from moving the probe through regions of the field that are non-uniform.

(10) The face of the meter should be coated with a transparent, conductive film to eliminate false readings due to the accumulation of static charge from the meter itself.

(11) The instrument should be battery operated with easily replaceable or rechargeable batteries. A test switch or some other means should be provided to determine whether the batteries are properly charged. The instrument should be capable of operating within the stated accuracy range for a time sufficient to accomplish the desired measurements without recharging or replacing the batteries.

(12) The user should be aware of the response time of the instrument, *i.e.*, the time required for the instrument to reach a correct reading.

(13) The device should be stable enough that frequent readjustment to zero ("rezeroing") is not necessary. If not equipped with automatic zeroing capability, devices must be zeroed with the probe out of the field, either by shielding the probe or turning off the RF source(s). Either method is time consuming, making stability an especially desirable feature.

(14) If the instrument is affected by temperature, humidity, pressure, *etc.*, the extent of the effect should be known and taken into account.

(15) The antenna elements should be sufficiently small and the device should be free from spurious responses so that the instrument responds correctly to the parameter being measured, both in the near-field and in the far-field. It should be emphasized that an instrument with a readout expressed in terms of power density will only be correct in the far-field. However, the term "far-field equivalent" or "plane-wave equivalent" power density is sometimes used in this context and would be acceptable as long as its meaning is understood and it is applied appropriately to the situation of interest (see discussion in Section I).

(16) The instrument should respond to the average (rms) values of modulated fields independent of modulation characteristics.

(17) The instrument should be durable and able to withstand shock and vibration associated with handling in the field or during shipping. A storage case should be provided.

(18) The accuracy of the instrument should not be affected by exposure to light or other forms of radiation.

(19) The markings on the meter face should be sufficiently large to be read easily at arm's length.

(20) Controls should be labeled clearly and kept to a minimum. Operating procedures should be relatively simple.

Narrowband devices may be used to characterize RF fields for exposure assessment. In contrast to broadband devices, narrowband instruments may have bandwidths of only a few hundred kHz or less. Narrowband instruments may be tuned from frequency to frequency, and the field level at each frequency measured. Or, in the case of a spectrum analyzer, the instrument may be set for the entire band to be measured and the magnitude of individual frequency components read from a display. The results of all such measurements may then be combined to determine the total field. As with broadband instruments, narrowband devices consist of basically four components: an antenna, cables to carry the signal from the antenna, electronic circuitry to process the output from the antenna, and a readout device.

Narrowband instruments may use linear antennas, such as rods (monopoles), loops, dipoles, biconical or conical log spiral antennas, or aperture antennas such as pyramidal horns or parabolic reflectors. A knowledge of the gain, the antenna factor, or the effective area for a particular antenna provides a means for determining the appropriate field parameter from a measurement of voltage or power. Cable loss also must be taken into account. Tunable field strength meters and spectrum analyzers are appropriate narrowband instruments for measuring antenna terminal voltage or power at selected frequencies. Each has certain advantages and disadvantages. Spectrum analyzers can scan very rapidly a band of frequencies and display simultaneously the results of the scan. They may also show energy at unexpected frequencies possible to overlook with a tunable field strength meter. On the other hand, most spectrum analyzers are designed for laboratory use and are not well adapted to field use.

With the advent of the incorporation of current standards in the ANSI/IEEE guidelines, devices for measuring at least induced currents have become available from commercial suppliers. The individual stands on a platform consisting of two parallel conductive plates. By measuring the voltage drop across a resistor, or capacitor, between the two plates and applying an appropriate calibrating factor, the current can be read. Alternatively, a current transformer can be used to measure directly the current through the ankles to ground, although this may not be feasible at the higher frequencies, depending on the characteristics of the current transformer. Contact currents can be measured by inserting a current measuring device between the hand and the object to be tested. A metallic probe and current transformer may be used, or a metallic probe with insulated section bridged by an ammeter can measure the current into the hand.

Measurements

Before beginning a measurement survey it is important to characterize the exposure situation to the extent possible. An attempt should be made to determine:

(1) The frequency and maximum power of the RF source(s) in question, as well as any nearby sources.

(2) Duty cycle, if applicable, of the source(s).

(3) Areas that are accessible to either workers or the public.

(4) Locations of any nearby reflecting surfaces that could produce regions of field intensification ("hot spots").

(5) For pulsed sources, such as radar, the pulse width, repetition rate and scanning rate.

(6) If appropriate, antenna type(s), gain and beam width.

(7) Type of modulation of the source(s).

(8) Type of antenna polarization employed.

Maximum expected field levels should be estimated in order to facilitate the selection of an appropriate survey instrument. In many cases, the best procedure may be to begin by using a broadband instrument capable of measuring accurately the total field from all sources in all directions. If the total field does not exceed the relevant exposure guideline in accessible areas, and if the measurement technique is sufficiently accurate, such a determination would constitute a showing of compliance with that particular guideline, and further measurements would be unnecessary.

Following are quotations from the Measurement Procedures section (6.6) of ANSI/IEEE C95.1-1992:

"In exposure situations where the distribution of field strengths or plane-wave equivalent power densities is substantially non-uniform over the body (partial-body exposure), for frequencies less than 300 MHz, determination of compliance with the MPE field limits may be determined by a spatial average of the exposure fields over the plane occupied by the body but in the absence of the body, where feasible. Nonuniform fields are commonly encountered in reflective conditions such as standing wave fields produced by reflection of fields from the earth or other reflective surfaces. Averaging may be accomplished through the use of real-time data-logging equipment, or via manually obtained point measurements.

"For practical measures of compliance with the standard, the average of a series of ten field strength measurements performed in a vertical line with uniform spacing starting at ground level up to a height of 2 m shall be deemed sufficient. In practice, this means that field strength measurements shall be made at heights above ground separated by 20 cm. Additional field strength data, for example, as obtained through the use of data-logging or spatial averaging equipment, obtained at smaller spacings than 20 cm is acceptable and will provide more detail on the spatial distribution of the fields."

"Measurements to determine adherence to the recommended MPEs should take into account the fact that several factors influence the response of measurement probes to the field which exists at any point in space. These factors include the following:

(1) variation of probe impedance with proximity to nearby reflective surfaces,
(2) capacitive coupling between the probe and the field source, and
(3) nonuniform illumination of the sensing elements that make up the probe (for example, the three orthogonal elements that comprise an isotropic, broadband electric field probe).

"The influence of each of these factors, which can result in erroneous measurements of field strengths, can be eliminated by maintaining an adequate separation distance between the probe elements and the field source. Accordingly, measurements should be made at a distance equal to three-probe dimensions between the surface of the nearest probe element and any object or 20 cm, whichever is greater."

In many situations there may be several RF sources. For example, a broadcast antenna farm or multiple-use tower could have several types of RF sources including AM, FM, and TV as well as land-mobile and microwave transmitters. In such a situation it is generally useful to use both broadband and narrowband instrumentation to fully characterize the electromagnetic environment. Broadband instrumentation could be used to determine what the overall field levels appear to be, while narrowband instrumentation would be required to determine the relative contributions of each signal to the total field.

At frequencies above 300 MHz measurement of only the electric field (E) is sufficient. At frequencies below 30 MHz, both the electric (E) field and magnetic (H) field must be measured. At frequencies between 30 and 300 MHz, analysis may show that measurement of only one field is necessary to show compliance with the MPE. Such an analysis would require confirmation that the location of interest is in the far field.

In many situations a relatively large sampling of data will be necessary to resolve spatially areas of field intensification that may be caused by reflection and multipath interference. Areas that are normally occupied by personnel or are accessible to the public should be especially examined to determine the exposure potential.

If narrowband instrumentation and a linear antenna are used, field strengths at three mutually orthogonal orientations of the antenna must be obtained at each measurement point. The values of E^2 or H^2 will then be equal to the sum of the squares of the corresponding orthogonal field components.

If an aperture antenna is used, it should be rotated in both azimuth and elevation until a maximum is obtained. The antenna should then be rotated around its longitudinal axis and the measurement repeated so that both horizontally and vertically polarized field components are measured. When using aperture antennas in reflective or near-field environments, significant negative errors may be obtained.

When making measurements, procedures should be followed which minimize possible sources of error. For example, when the polarization of a field is known, all cables associated with the survey instrument should be held perpendicular to the electric field to minimize pickup. Ideally, non-conductive cable, *e.g.*, optical fiber, should be used, since substantial error can be introduced by cable pickup.

Interaction of the entire instrument (probe plus readout device) with the field can be a significant problem below approximately 10 MHz. The use of a self-contained meter may be desirable for measuring electric field at these frequencies. Also, at frequencies below about 1 MHz, the body of the person making the measurement may become part of the antenna. Error from probe/cable pickup and instrument/body interaction can be reduced by supporting the probe and electronics on a dielectric structure made of wood, styrofoam, *etc.* In this connection, the removal of all unnecessary personnel from the area is desirable where a survey is being conducted in order to minimize errors due to reflection and field perturbation.

In areas with relatively high fields, or pulsed fields with high peak powers, a good idea is occasionally to hold the probe fixed, rotate the readout device, and move the connecting cable while observing the meter reading. Any significant change usually indicates pickup in the leads and interference problems. When a field strength meter or spectrum analyzer is used in the above environments, the antenna cable should be removed occasionally and replaced with an impedance matched termination. Any reading on the device indicates pickup or interference.

Substantial errors may be introduced due to zero drift. If a device requiring zeroing is being used, frequent checking for drift should be done with the probe shielded with metal foil, with the source(s) shut off, or with the probe removed from the field.

Multiple-Use Sites

Multiple RF transmitters are often found at a given location. In many cases, so many antennas are clustered together that the term "antenna farm" is used to describe the site. Such locations may include several RF sources such as radio and television broadcast towers, land-mobile transmitters, and microwave point-to-point links. Since the biological effects of RF radiation are related to the total energy absorbed by the body, contributions from all significant sources of such energy must be considered in evaluating the potential for exposure at a given location.

"Significant" sources of energy have been determined to be those that contribute more than one percent of the ANSI/IEEE MPE to the electromagnetic environment[15]. In instances where a new facility is being added to a multiple-use site or a change is being made in an existing facility determined to contribute more than one percent of the MPE to the electromagnetic environment, a complete evaluation must be made of the overall exposure level. The RF environment is likely to be quite complex. Although the configuration of radiating facilities may be such that a paper analysis may be possible, many situations are likely to require careful measurements in and around the site in order to determine whether a potential exists for exposure in excess of the guidelines.

At multiple-use sites the responsibility for evaluating the RF environment usually lies with the newcomer or the user proposing a change in facilities. At the time of license renewal, when the licensees must certify compliance with the environmental rules, all users are jointly responsible for evaluating whether or not the site complies with the guidelines and, if not, for the measures necessary to bring the site into compliance. Under Section 0.314 of the FCC Rules and Regulations the Engineer in Charge at each FCC field installation has the authority to:

> "[r]equire special equipment and program tests during inspections or investigations to determine compliance with technical requirements specified by the Commission."[16]

At multiple-use sites where measurements are judged to be necessary, the Engineer in Charge could require all licensees to cooperate in the making of such measurements. This could include requiring on/off tests or, if available, the use of auxiliary transmitters.

With regard to compliance with the ANSI/IEEE guidelines, in mixed or broadband fields where several sources and frequencies are involved, the fraction of the recommended limit incurred

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[15] See Section 1.1307(b) Note 2 of the FCC Rules and Regulations.

[16] 47 C.F.R. §0.314(h).

within each frequency interval should be determined, and the sum of all fractional contributions should not exceed 1.0 (See Sections 4.1.1(e) and 4.1.2(e) of Appendix A). For example, if in a controlled environment location FM broadcast station A contributes 400 $\mu W/cm^2$ (2/5 or 40% of the limit in the FM band), FM broadcast station B contributes 200 $\mu W/cm^2$ (1/5 or 20% of the limit, and a UHF-TV station operating on channel 35 (center frequency = 599 MHz) contributes 400 $\mu W/cm^2$ (1/5 or 20% of the limit for its frequency), then relative to the ANSI/IEEE guidelines the total level will be 4/5 or 80% of the guidelines, which, assuming no other contributions, would be in compliance with ANSI/IEEE's recommendations.

Section IV: CONTROLLING EXPOSURE TO RF FIELDS

Uncontrolled Environmental Exposure

Studies by EPA (see Reference 21) have shown that the great majority of the American public is exposed to insignificant levels of RF radiation. However, there are some situations in which RF levels are considerably higher than what prevails generally. In some cases preventive measures may have to be taken. ANSI/IEEE provides maximum permissible exposure (MPE) uncontrolled environment guidelines specifically for "...exposure of individuals who have no knowledge or control of their exposure...[which] may occur in living quarters or workplaces."[17] The uncontrolled environment criteria do not apply to "...exposure that is the incidental result of passage through areas where analysis shows the exposure levels may be above [the MPE for uncontrolled environments] but do not exceed [the MPE for controlled environments]."[18] The potential for higher than usual levels of exposure is more likely to occur in controlled than uncontrolled environments but situations may exist where measures must be taken to avoid exceeding the MPE for the uncontrolled environment. Such situations may include the existence of a nearby school or park playground, or on rooftops of nearby tall apartment or office buildings. If exposure in such instances may be a problem, several options are available for reducing the potential for exposure.

In order for the ANSI/IEEE protection guides, or any other protection guidelines, to be exceeded areas of excessive levels have to be accessible. Confusion often exists over the difference between an emission standard, *e.g.*, a certain power density or field strength allowed at a certain distance, and an exposure standard. The ANSI/IEEE guidelines constitute an exposure standard, *i.e.*, recommended levels to which people may be exposed safely regardless of where those levels occur. As long as accessibility to an area of excessive RF levels is restricted to conform with the ANSI/IEEE guidelines, those guidelines would not be violated.

The easiest ways to restrict accessibility are: (1) fencing and posting areas where RF fields

[17] ANSI/IEEE C95.1-1992, Section 4.1.2.

[18] ANSI/IEEE C95.1-1992, Section 4.1.1.

may exceed the standard,[19] or (2) restricting the time that individuals other than those engaged in the operation or maintenance of facilities could have access to such areas. Time restrictions would have to take into account the time-averaging provisions such as ANSI/IEEE's. The ANSI/IEEE protection guides are based on averaging exposures over periods which vary by frequency. At frequencies applicable to FM and broadcast stations, the averaging time in uncontrolled environments is 30 minutes. Throughout most of the AM band the averaging time for uncontrolled environments is 6 minutes but the averaging time rises above 1340 kHz, rising to 9.6 minutes at 1700 kHz.

Although simply restricting access to areas where high RF levels are present may offer the simplest and most cost-effective solutions, other methods are available for reducing the potential for exposure to RF fields. With regard to FM broadcast facilities, EPA has found that several corrective measures may be taken to reduce the possibility of non-compliance with a given exposure standard (see Reference 5). Examination of measured elevation patterns for several different types of FM antennas has shown that some antennas direct much less radiation downward than others. Therefore, in some cases a simple change of antenna to a "better" one may be all that is needed to reduce ground-level exposure below a given level. In general, antennas manufactured after the mid-1980s are of the "better" type.

A more expensive, but effective, approach for FM antennas involves modifying the vertical plane radiation pattern by reducing the spacing between radiating elements. The vertical plane radiation pattern of an FM antenna is the product of the element pattern and the array pattern. FM antennas typically use one-wavelength spacing between elements. Because the field from each element adds in phase with all other elements, at points directly beneath the elements the array pattern produces results in downward radiation equal to that in the main beam. If the spacing between elements is reduced to one-half wavelength, and an even number of bays is employed, each element field will have a counterpart which is out-of-phase. This will result in a substantial reduction in the energy directed toward the ground.

The disadvantage of this method is that, for a given number of bays, the reduced aperture that occurs with one-half wavelength spacing reduces the overall gain of the antenna. To maintain the original gain of the antenna, the number of elements (bays) must be increased, usually doubled. Alternatively, the spacing between elements could be reduced so that the field from element (n) and from element (N/2 + n) are exactly out of phase, where n is a particular element in an array with a total of N bays.

Use of the latter method results in a smaller increase in the total number of bays necessary. However, as noted by EPA, the feeding of such an array is more difficult since the length of the transmission line between bays determines phasing. For one-half wavelength spacing, criss-crossing the transmission line or turning alternate elements upside down will yield proper phasing.

Reference 5 contains a table showing suggested interbay spacings required to reduce downward radiation in the array pattern of FM antennas. The optimum spacing may differ for different types of antennas. Coupling effects may occur at spacings less than one wavelength that are not easy to predict theoretically. EPA has studied this problem. Reference 5 contains figures showing

[19] For information on appropriate warning symbols for RF radiation hazards see References 22 and 23.

the effects of altering spacing for three commercially available FM antenna elements. Such data are available also from the manufacturers of FM antennas.

Another possible method for reducing downward radiation involves using one and one-half wavelength spacing between elements. This method results in little change in antenna gain.

Other actions that could be taken to reduce the potential for excessive exposure would be raising the height of an FM or TV antenna or relocating a broadcast tower. However, such actions would have to take into account other factors including signal coverage, land use limitations, air traffic safety and the permissible separations to other broadcast stations.

For television broadcast antennas, EPA identified two methods for reducing potential exposure, besides the obvious method of restricting access discussed above. The first measure that might be taken, as with FM antennas, would be a change of antenna. EPA verified, for example, that arrays for VHF-TV antennas can be designed to minimize downward radiation to as little as 7% of the main beam field. However, such antennas may be at least twice as expensive as standard antennas. As mentioned previously, antennas used for UHF-TV have very high gain in the main beam and radiate relatively little directly down toward the ground. Therefore, these antennas already are designed for minimum downward radiation. The remaining option for both VHF-TV and UHF-TV antennas would be an increase in antenna height above ground. However, this could involve the same difficulties as discussed above with regard to FM broadcast facilities.

Controlled Environmental Exposure

Controlled environmental exposures may involve individuals required to be near the RF source for at least part of a work day. This may or may not be a problem depending on the amount of time the individual is exposed. An important factor to be remembered is that the ANSI/IEEE standard is time-averaged, *i.e.*, the time of exposure must be taken into account when evaluating a given situation. For example, walking within a few meters of an AM broadcast tower at a normal pace might not involve excessive exposure, but remaining in that field for an extended period of time could result in the time-averaged field strength exceeding permissible levels for the AM band.

The ANSI/IEEE guidelines specify that exposure in controlled environments is to be averaged over any six-minute period for exposure to fields at frequencies below 15,000 MHz. For example, a worker could be exposed to twice the ANSI/IEEE levels for three consecutive minutes as long as during the subsequent three minutes he or she would not be exposed at all. Whenever work must be carried out such that the average exposure over six minutes would exceed the ANSI/IEEE limits, exposure must be reduced by some other means. This could be accomplished by spreading the work out over a longer period of time, thus reducing average exposure below the acceptable level, by switching to an auxiliary system (if available) while work on the main system is in progress, by scheduling work when the system is operating at reduced power or is shut down, or possibly by shielding the worker from the source. Protective clothing fabricated from conductive material may prove useful. One recently introduced material[20] consisting of polyester and stainless steel threads in a cotton wrap has been tested extensively and endorsed by the Occupational Safety and Health Administration (OSHA)[21] as providing compliance with ANSI/IEEE at power densities of 20 mW/cm^2 for frequencies to 60 MHz and at power densities of 125 mW/cm^2 for frequencies from 65 MHz to 10 GHz. This material endorsed by OSHA avoids the problems encountered with such clothing in the past due to excessive heating of the fabric in the presence of high RF fields.

In broadcast environments, many work place locations, such as offices and studios, are classified properly as "uncontrolled"; however, transmitter buildings in close proximity to radiating systems, transmitters used at multistation locations, and work requiring close proximity to radiating elements are clearly "controlled environment" locations that may require special treatment. For example, measurements of RF fields made in the immediate vicinity of the radiating elements of FM broadcast antennas have shown that field levels can be significantly higher than the ANSI/IEEE protection guides (see Reference 24).

For AM broadcast systems, electric and magnetic field strengths near a monopole antenna drop off rapidly with increasing distance. Even for a 50 kW transmitter, distances from a tower of less than fifteen meters are required before field strengths are likely to approach the ANSI/IEEE limits (see Tables 1 and 1A in Appendix D). For multiple tower arrays the spacing between adjacent towers would not, in general, be less than 40 meters, even at the highest AM frequencies, so that, as one tower is approached, the contribution of field strength from other towers in the array would decrease to relatively insignificant levels. If work on or immediately adjacent to a tower is required, the designation of zones within which a worker may remain for specified periods of time may be appropriate for compliance with the ANSI/IEEE or other guidelines. (See also pages 21 and 22 and Appendix E.)

Tuning circuits for AM broadcast towers have been identified as a source of locally intense magnetic fields (Reference 25). These magnetic fields decrease rapidly with distance from the tuning circuits but should be considered when evaluating exposure near the base of AM towers. However, the ANSI/IEEE 1992 magnetic field standard for the AM broadcast band in terms of equivalent far-field power density, is substantially less stringent than the electric field standard in the same terms. Accordingly, the electric field is the normal determinant of distances from AM towers providing compliance with the guidelines. When necessary, care given to placement of the tuning circuits with respect to personnel access should assure compliance.

With regard to maintenance of FM and TV broadcast transmitters and antennas, two situations are of particular interest and should be noted. Because currents and voltages in power amplifier cabinets can be lethal, cabinet doors are interlocked and must be closed when the transmitter is on. However, at multiple station locations high RF field strengths can be encountered even when the transmitter being worked on is completely shut down. This is because the antenna for a particular station is likely to pick up high levels of energy from other stations. That energy can be conducted

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[20] NAPTEX®, a fabric woven in Europe, and formed into garments sold by Maxwell Safety Products, Ltd., 20 Gilbert Avenue, Hauppauge, NY 11788

[21] Letter of April 14, 1993, from the Director, Directorate Technical Support, OSHA, to Dr. Thomas P. Stanley, FCC Chief Engineer.

to the final amplifier cubicle and produce high field strengths in the vicinity of the cubicle. If measurements are to be made in a multistation environment, this factor should be evaluated. If such induced field strength levels are found to be a problem, they should be reducible to acceptable levels by either opening the RF transmission line leading to the antenna or by bypassing the center conductor to ground of the coaxial line wherever access can be achieved conveniently.

Section V: **REFERENCES**[22]

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APPENDIX A

ANSI/IEEE RADIATION GUIDELINES

NOTICE

Relevant sections of the "ANSI/IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz" (ANSI/IEEE C95.1-1992) are listed below. ANSI/IEEE C95.1-1992 has been copyrighted (1992) by the Institute of Electrical and Electronics Engineers, Inc., and cannot be distributed by NAB. Complete copies of the standard are available from:

American National Standards Institute 1430 Broadway New York, NY 10018	or	Standards Sales - IEEE 445 Hoes Lane Piscataway, NJ 08854

ANSI/IEEE STANDARD FOR SAFETY LEVELS WITH RESPECT TO HUMAN EXPOSURE TO RADIO FREQUENCY ELECTROMAGNETIC FIELDS, 3 kHz TO 300 GHz

(replacing pages 38-53)

APPENDIX B

FM BROADCAST

Tables and Figures

(NOTE: See text in Section II for instructions on use)

TABLE 1

MINIMUM HEIGHTS FOR SINGLE FM ANTENNAS (METERS ABOVE GROUND TO CENTER OF RADIATION) REQUIRED FOR COMPLIANCE WITH ANSI/IEEE C95.1-1992 EXPOSURE GUIDELINES ANYWHERE ON THE GROUND FOR CONTROLLED AND UNCONTROLLED ENVIRONMENTS
(*see notes below)

ERP (H+V)	Number of Bays											
In kW	2.00		4.00		6.00		8.00		10.00		12.00	
	Controlled	Uncontrolled	Controlled	Uncontrolled	Controlled	Uncontrolled	Controlled	Uncontrolled	Controlled	Uncontrolled	Controlled	Uncontrolled
0.5	4.10	9.17	4.10	9.17	4.10	9.17	4.10	9.17	4.10	9.17	4.10	9.17
	1.90	4.25	1.20	2.68	1.00	2.24	1.00	2.24	0.90	2.01	0.90	2.01
3	10.00	22.36	10.00	22.36	10.00	22.36	10.00	22.36	10.00	22.36	10.00	22.36
	4.70	10.51	2.90	6.48	2.60	5.81	2.40	5.37	2.30	5.14	2.20	4.92
10	18.30	40.92	18.30	40.92	18.30	40.92	18.30	40.92	18.30	40.92	18.30	40.92
	8.60	19.23	5.30	11.85	4.70	10.51	4.40	9.84	4.20	9.39	4.00	8.94
25	28.90	64.62	28.90	64.62	28.90	64.62	28.90	64.62	28.90	64.62	28.90	64.62
	13.60	30.41	8.40	18.78	7.40	16.55	6.90	15.43	6.60	14.76	6.30	14.09
50	40.90	91.45	40.90	91.45	40.90	91.45	40.90	91.45	40.90	91.45	40.90	91.45
	19.30	43.15	11.90	26.61	10.50	23.48	9.70	21.69	9.30	20.79	8.90	19.90
75	50.00	111.80	50.00	111.80	50.00	111.80	50.00	111.80	50.00	111.80	50.00	111.80
	23.60	52.77	14.60	32.65	12.80	28.62	11.90	26.61	11.40	25.49	10.90	24.37
100	57.80	129.24	57.80	129.24	57.80	129.24	57.80	129.24	57.80	129.24	57.80	129.24
	27.30	61.04	16.90	37.79	14.80	33.09	13.80	30.86	13.10	29.29	12.60	28.17
125	64.60	144.45	64.60	144.45	64.60	144.45	64.60	144.45	64.60	144.45	64.60	144.45
	30.50	68.20	18.90	42.26	16.60	37.12	15.40	34.43	14.70	32.87	14.10	31.53
150	70.80	158.31	70.80	158.31	70.80	158.31	70.80	158.31	70.80	158.31	70.80	158.31
	33.40	74.68	20.70	46.29	18.10	40.47	16.90	37.79	16.10	36.00	15.40	34.43
175	76.40	170.83	76.40	170.83	76.40	170.83	76.40	170.83	76.40	170.83	76.40	170.83
	36.10	80.72	22.30	49.86	19.60	43.83	18.20	40.70	17.40	38.91	16.70	37.34
200	81.70	182.68	81.70	182.68	81.70	182.68	81.70	182.68	81.70	182.68	81.70	182.68
	38.60	86.31	23.90	53.44	21.00	46.96	19.50	43.60	18.60	41.59	17.80	39.80

*NOTES: (1) Above numbers apply to single FM antennas in which base of supporting tower is at approximately the same level or higher than surrounding terrain.

(2) For each entry, higher number represents "worst case", i.e., dipole element, and lower number represents "best case" achievable using typically available antennas.

Figure 1. Plane-wave equivalent power density normalized to 1 kW total ERP (H+V) for FM antennas having 2,4,6,8,10, and 12 bays. Antenna height to center of radiation = 10 m

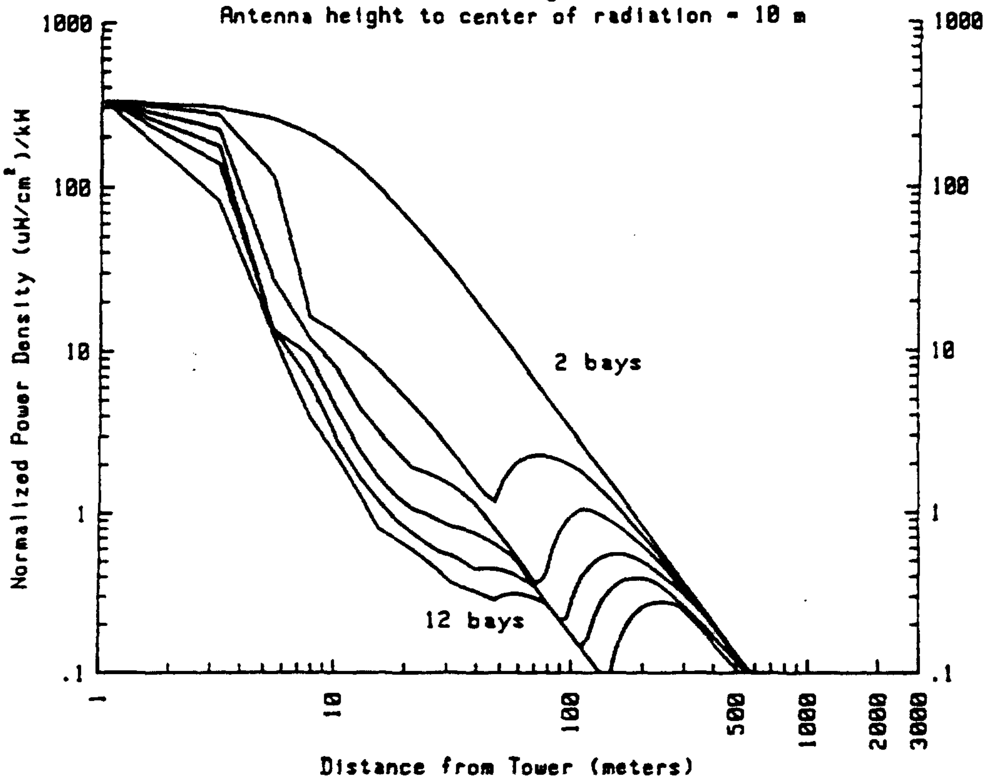


Figure 2. Plane-wave equivalent power density normalized to 1 kW total ERP (H+V) for FM antennas having 2,4,6,8,10, and 12 bays. Antenna height to center of radiation = 20 m

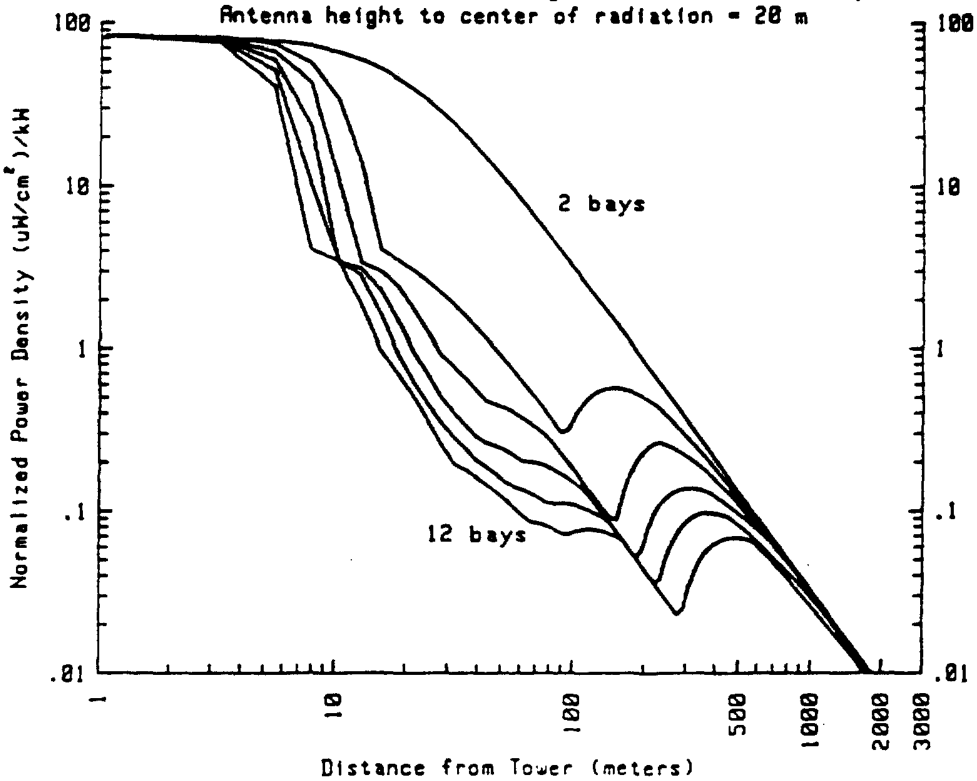


Figure 3. Plane-wave equivalent power density normalized to 1 kW total ERP (H+V) for FM antennas having 2,4,6,8,10, and 12 bays. Antenna height to center of radiation = 30 m

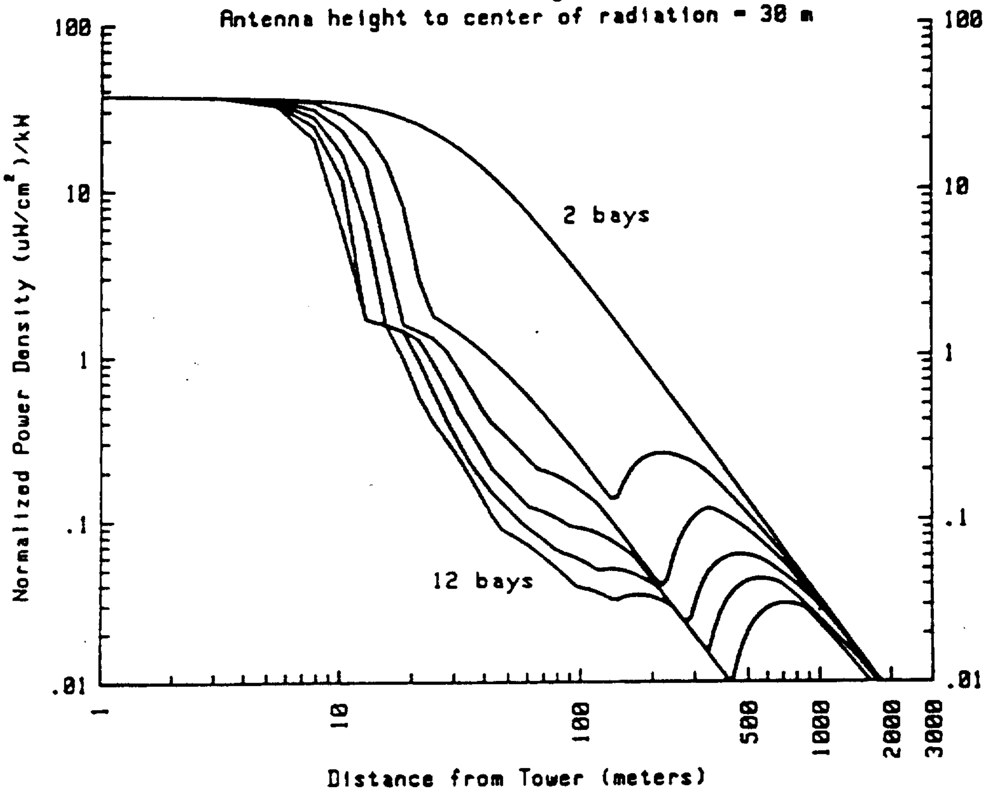


Figure 4. Plane-wave equivalent power density normalized to 1 kW total ERP (H+V) for FM antennas having 2,4,6,8,10, and 12 bays. Antenna height to center of radiation = 40 m

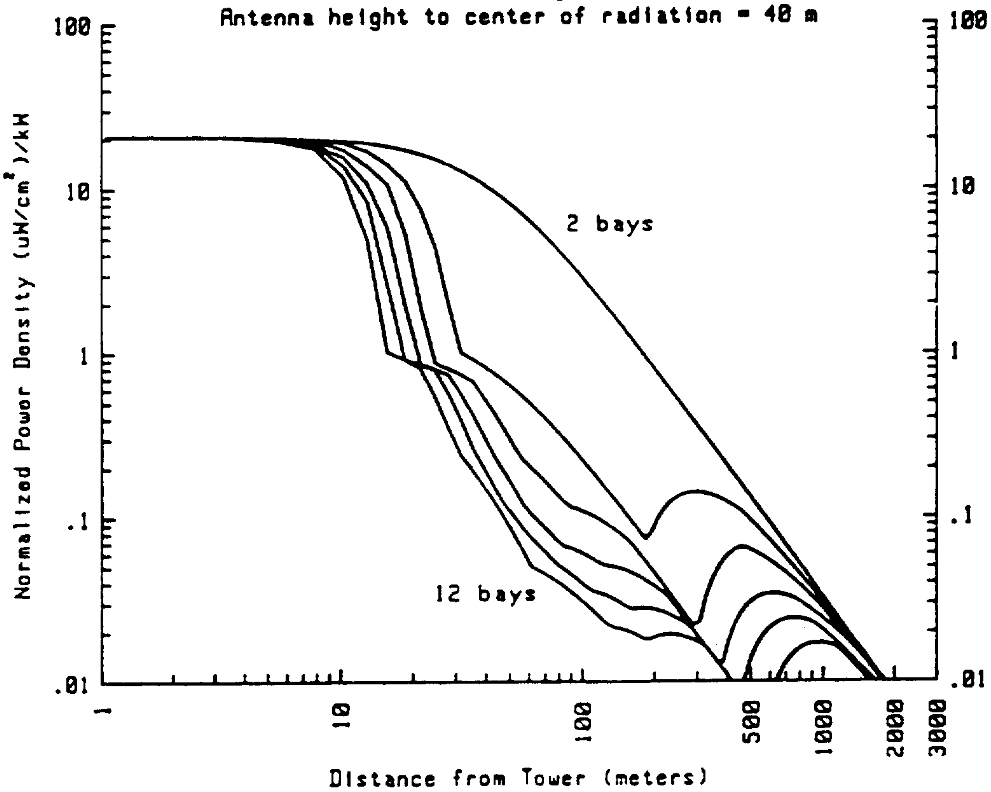


Figure 5. Plane-wave equivalent power density normalized to 1 kW total ERP (H+V) for FM antennas having 2,4,6,8,10, and 12 bays. Antenna height to center of radiation = 50 m

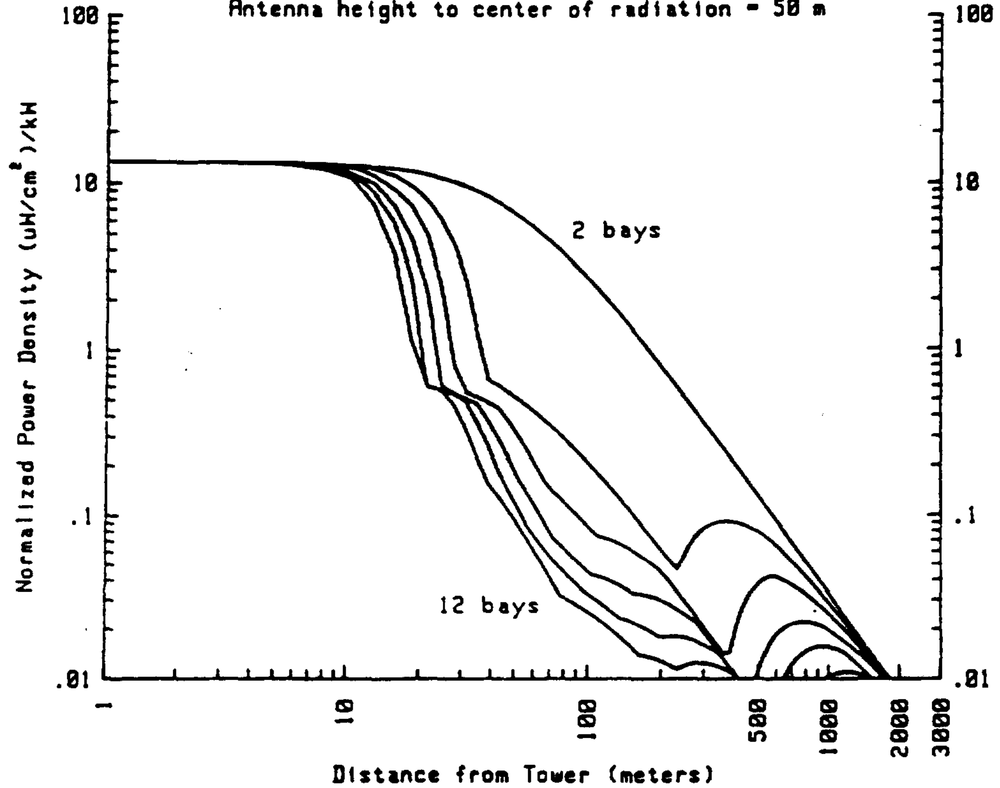


Figure 6. Plane-wave equivalent power density normalized to 1 kW total ERP (H+V) for FM antennas having 2,4,6,8,10, and 12 bays. Antenna height to center of radiation = 60 m

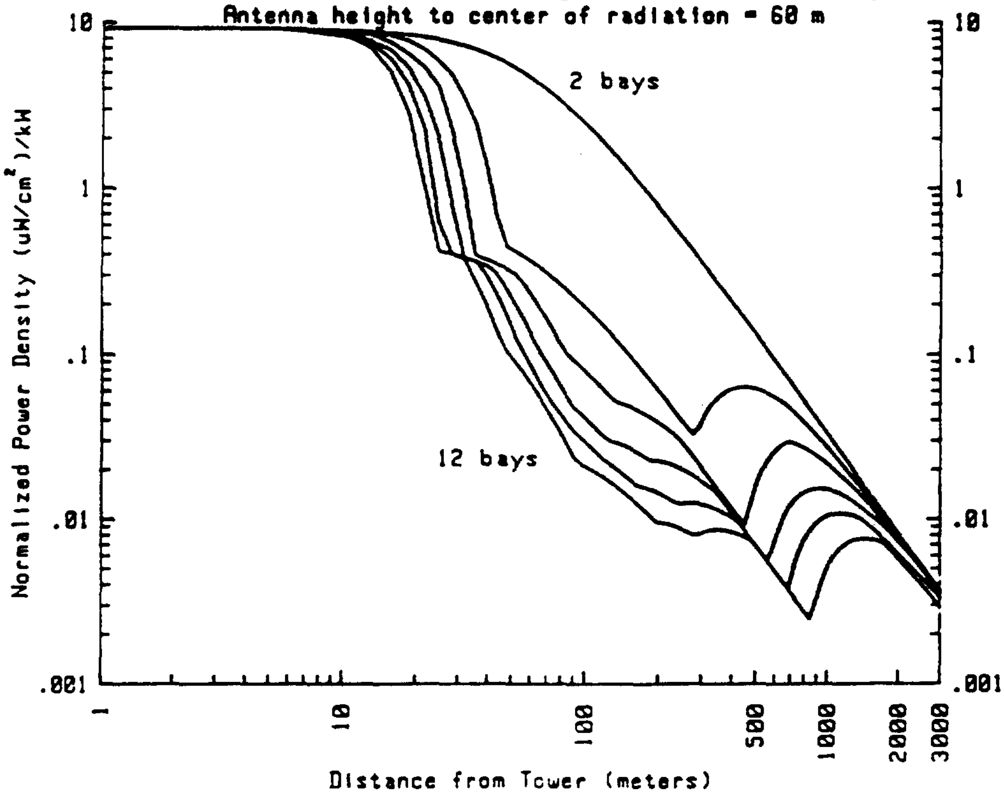


Figure 7. Plane-wave equivalent power density normalized to 1 kW total ERP (H+V) for FM antennas having 2,4,6,8,10, and 12 bays. Antenna height to center of radiation = 70 m

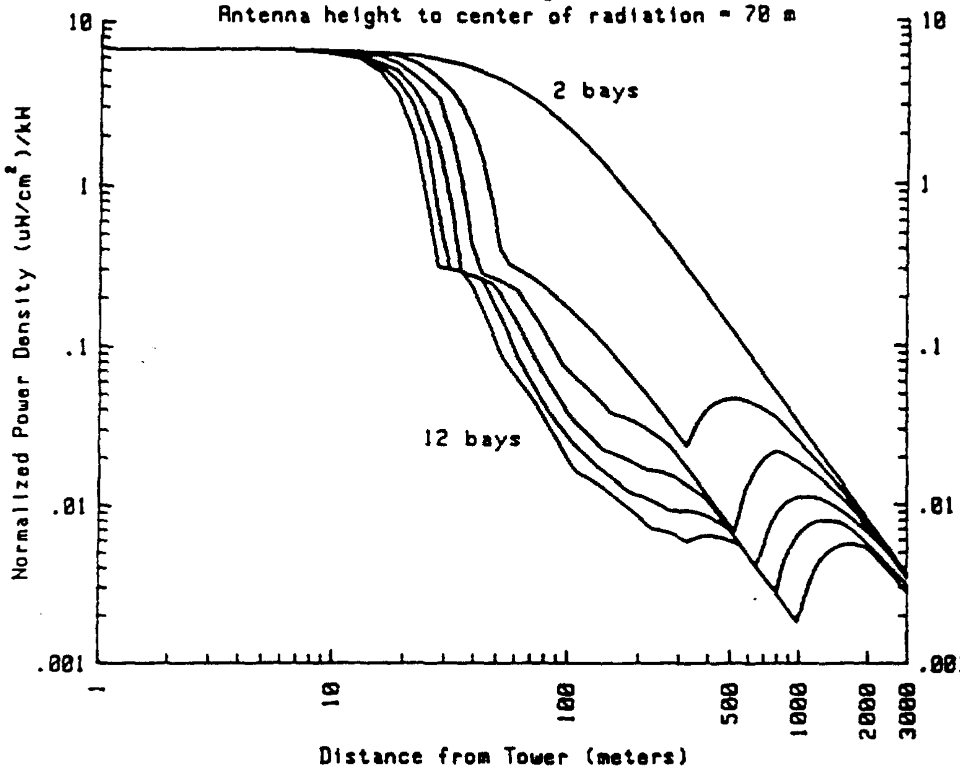


Figure 8. Plane-wave equivalent power density normalized to 1 kW total ERP (H+V) for FM antennas having 2,4,6,8,10, and 12 bays. Antenna height to center of radiation = 80 m

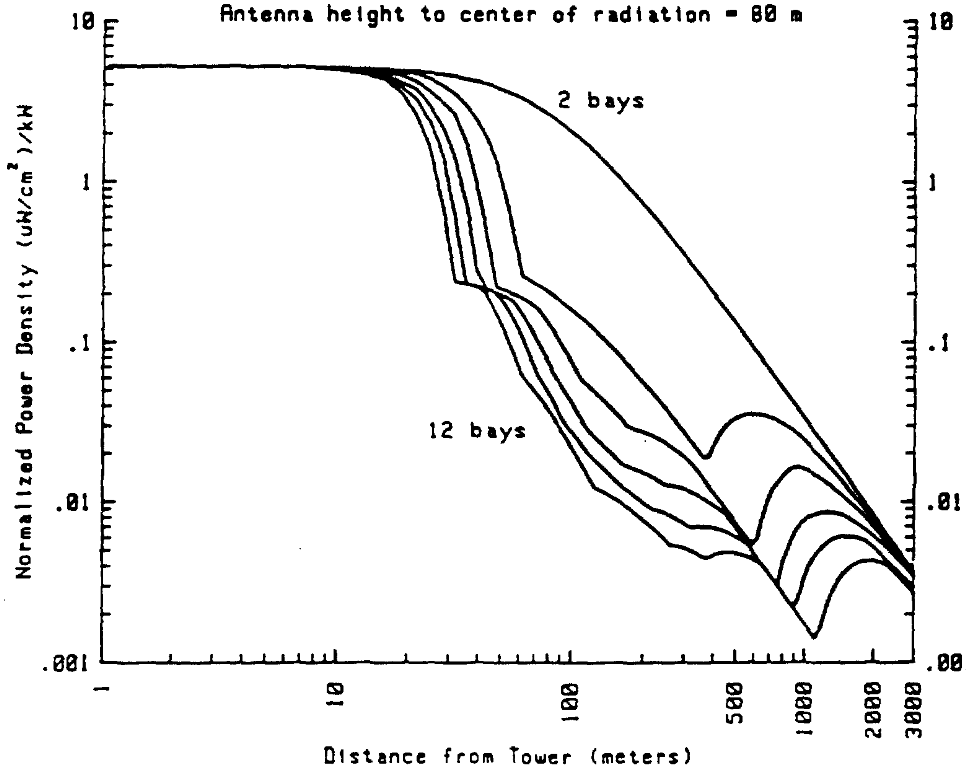


FIGURE 9a: MINIMUM DISTANCE IN MAIN BEAM FROM SINGLE FM ANTENNAS (METERS FROM CENTER OF RADIATION) REQUIRED FOR COMPLIANCE WITH ANSI / IEEE C95.1-1992 CONTROLLED ENVIRONMENT EXPOSURE GUIDELINES

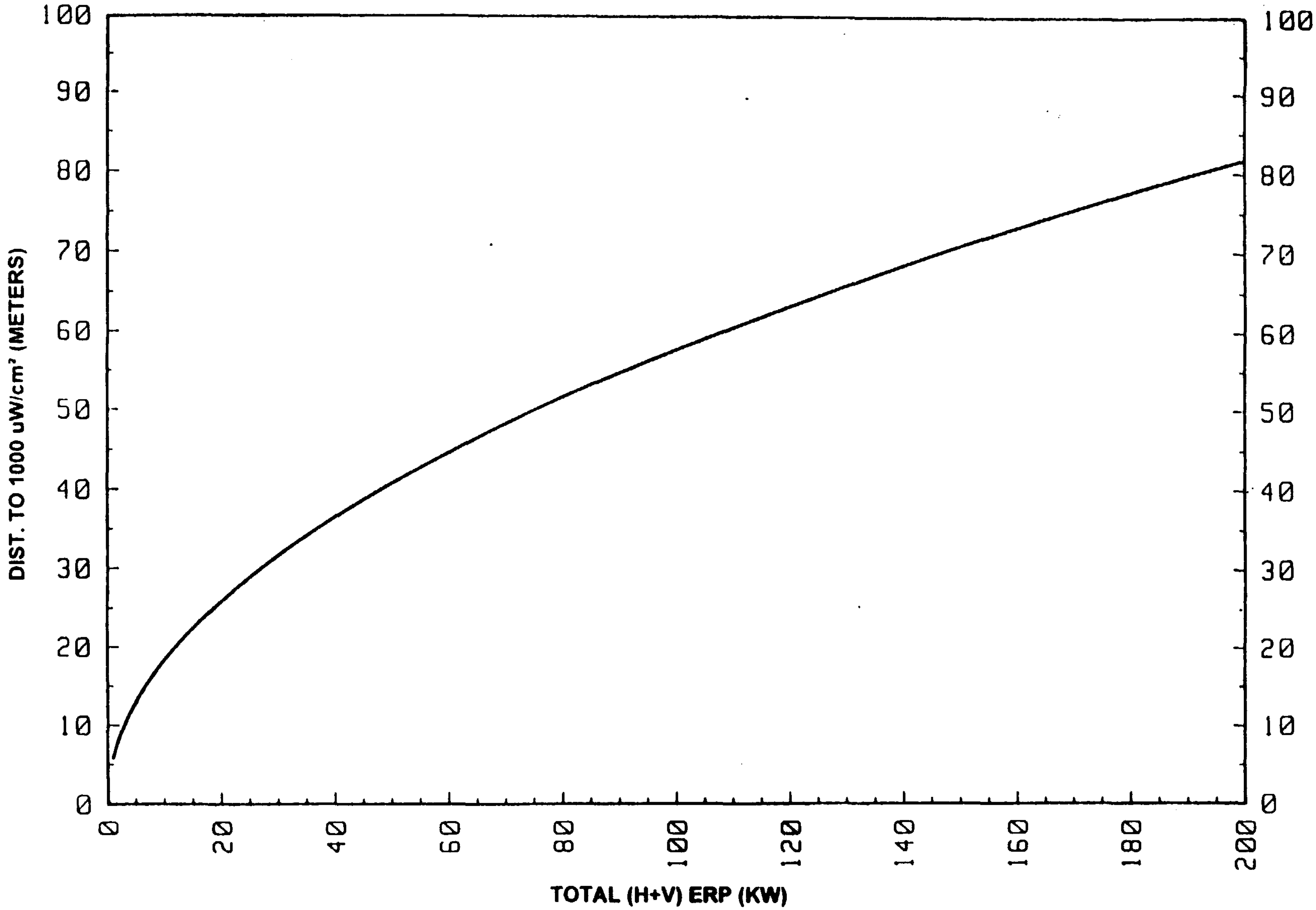
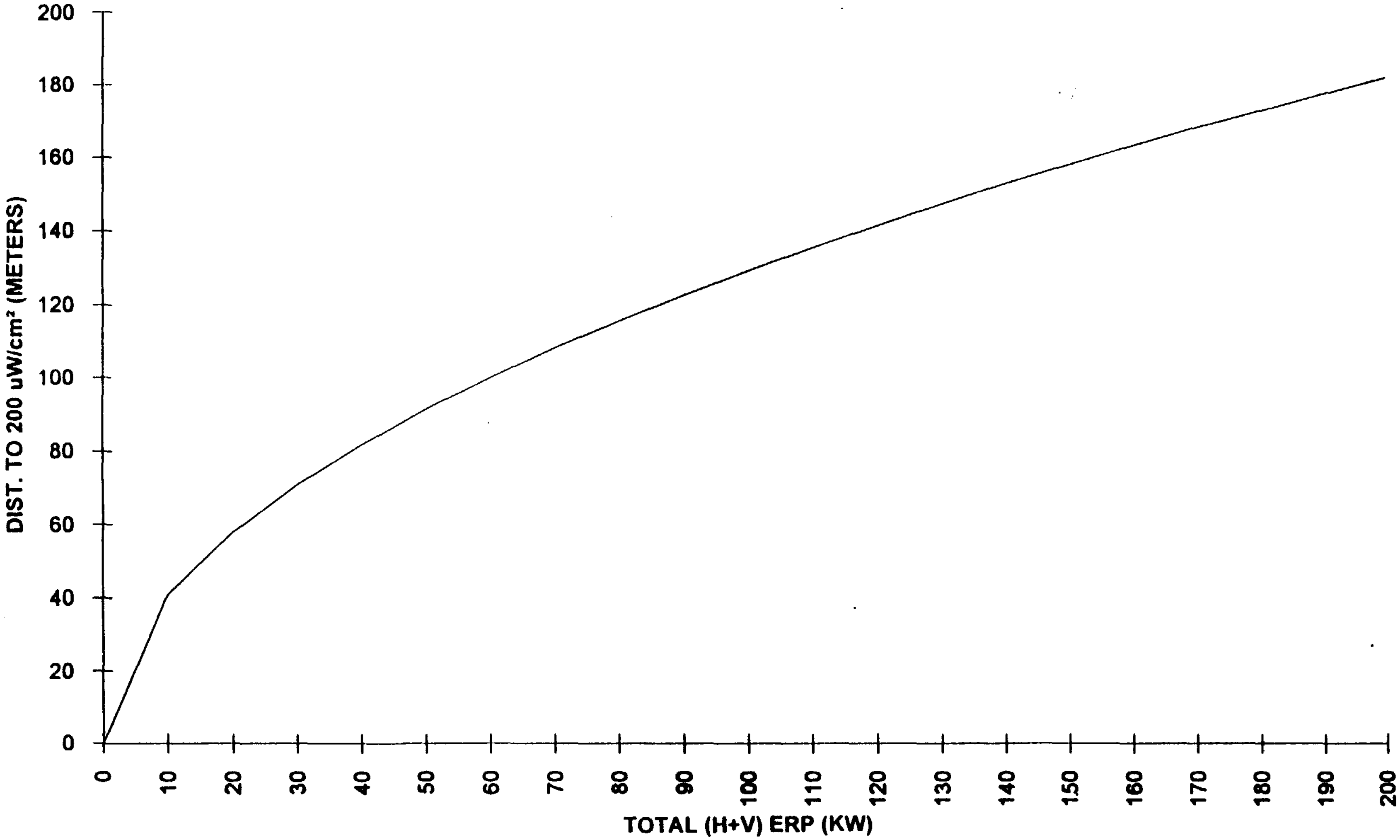


FIGURE 9b: MINIMUM DISTANCE IN MAIN BEAM FROM SINGLE FM ANTENNAS (METERS FROM CENTER OF RADIATION) REQUIRED FOR COMPLIANCE WITH ANSI / IEEE C95.1-1992 UNCONTROLLED ENVIRONMENT EXPOSURE GUIDELINES



APPENDIX C

TV BROADCAST

Tables and Figures

(NOTE: See text in Section II for instructions on use)